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Photon and electron structure from e^+e^- interactions[†]

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Abstract

The status of the measurements and the theoretical developments concerning the hadronic structure of the photon are briefly summarised.

1 Introduction

For more than 20 years measurements of photon structure functions give deep insight into the rich structure of a fundamental gauge boson, the photon. A recent review on this subject can be found in [1].

The main idea is that by measuring the differential cross-section

$$\frac{d^2\sigma_{\mathrm{e}\gamma\to\mathrm{e}X}}{dxdQ^2} = \frac{2\pi\alpha^2}{x\,Q^4}\left[\left(1+(1-y)^2\right)F_2^\gamma(x,Q^2) - y^2F_{\mathrm{L}}^\gamma(x,Q^2)\right]$$

one obtains the photon structure function F_2^γ, see Figure 1 for an illustration. Here Q^2 and P^2 are the absolute values of the four momentum squared of the virtual and quasi-real photons, with $P^2 \ll Q^2$. The symbols x and y denote the usual dimensionless variables of deep-inelastic scattering, and α is the fine structure constant. The flux of the incoming photons, $f_\gamma(z,P^2)$, where z is the fraction of the electron energy carried by the photon, is usually taken from the equivalent photon approximation, EPA. In leading order, the structure function F_2^γ is proportional to the parton content of the photon and therefore reveals the structure of the photon.

In the region of small y studied ($y \ll 1$), the contribution of the term proportional to $F_{\mathrm{L}}^\gamma(x,Q^2)$ is small, and is usually neglected. Because the energy of the quasi-real photon is not known, x has to be derived by measuring the invariant mass of the hadronic final state X, which is a source of significant uncertainties, and makes measurements of F_2^γ mainly limited by the systematic error, except for large values of Q^2.

At this conference new measurements of the hadronic structure function F_2^γ and its charm component $F_{2,\mathrm{c}}^\gamma$ have been presented. They are discussed, together with the most recent fits

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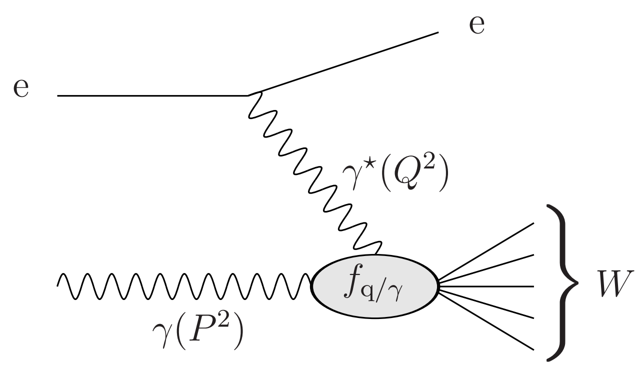

Figure 1: *Deep-inelastic electron photon scattering.*

to the F_2^γ data and the prospects for measurements of F_2^γ at a future Linear Collider. In addition, an attempt by DELPHI is presented to investigate the photon structure by measuring the electron structure function F_2^{e}.

2 Photon structure function

The improvement in the measurement of F_2^γ since the first result by PLUTO in 1981 is quite impressive, see Figure 2. The analysis of the LEP data has extended the kinematic coverage by about two orders in magnitude, both to larger Q^2 and to smaller x. In addition, due to continuous improvements of the analyses and a LEP combined effort to obtain a better description of the data by the Monte Carlo models, the precision of the measurements has been improved considerably.

For this conference the final OPAL result for the measurement of the hadronic structure function F_2^γ at high Q^2 has been available. This measurement is based on the complete LEP2 data and extends the measurement of F_2^γ to $\langle Q^2 \rangle = 780$ GeV^2, the largest scale ever probed. As can be seen from Figure 3 the measured F_2^γ is rather flat, and, within errors, the parameterisations from GRSc [2], SaS1D [3] and WHIT [4] are in agreement with the data.

The already available preliminary result from DELPHI [5] at a slightly lower $\langle Q^2 \rangle$ basically shows the same trend. Since the measurement at high Q^2 is mainly limited by the statistical error, it is very desirable to combine the OPAL result with the measurements to come from the other LEP experiments. To facilitate the combination, the analyses should be performed for the same bins in x and Q^2.

Also the investigation of the evolution of F_2^γ with Q^2 in ranges of x has been continued using the LEP2 data. For medium values of x, the precision of the OPAL results based on LEP1 data has been improved considerably by using the large luminosity available at LEP2 energies. With the present level of precision the data start to challenge the existing

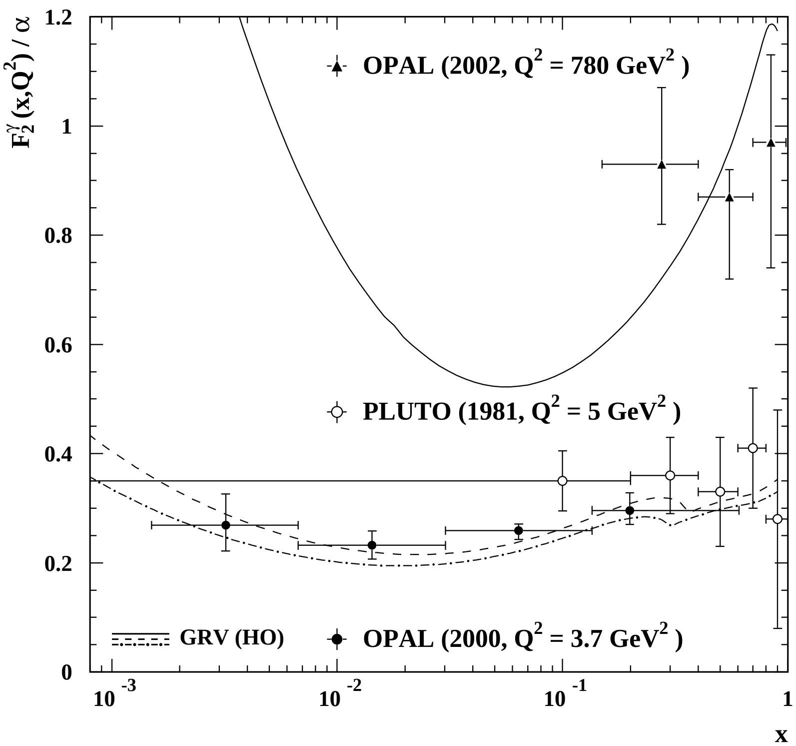

Figure 2: *The improvements in F_2^γ at LEP.*

parameterisations of F_2^γ. Given this, several theoretical as well as experimental issues have to be addressed in more detail when interpreting the data. Examples are the suppression of F_2^γ with P^2 and radiative corrections to the deep-inelastic scattering process. A summary of the present status of all measurements of the Q^2 evolution of F_2^γ is shown in Figure 5.

3 Fits to F_2^γ data

There have been recent fits [6] to F_2^γ based on all available data, except for the TPC/2γ results. To facilitate the analysis, some simplifications are made in the treatment of the experimental results. In the analysis the correlation matrix of the various points is used if it is provided by the experiment. However, the systematic errors are treated as uncorrelated, the P^2 effect and the radiative corrections are neglected, and finally, in case of asymmetric errors, the data points are moved to the central value and symmetric error are assumed. Given the precision of the data mentioned above, this procedure should most likely be improved for future analyses. The fits are done in a fixed flavour scheme with *uds* as active

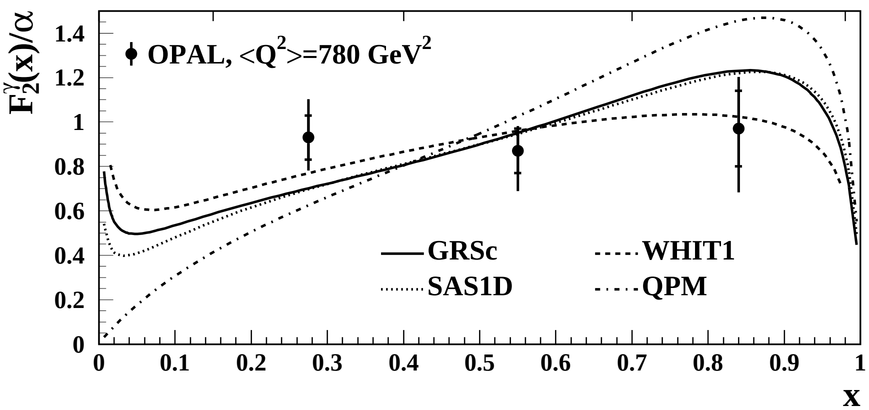

Figure 3: *The measurement of F_2^γ at high Q^2.*

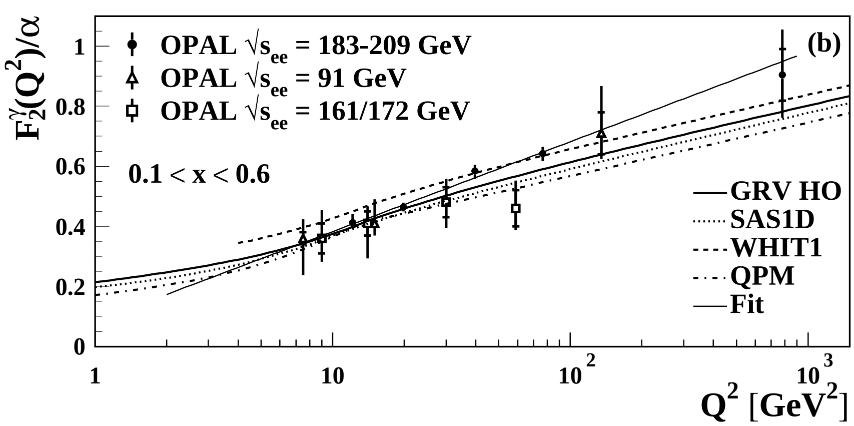

Figure 4: *The Q^2 evolution of F_2^γ from OPAL.*

flavours and charm treated as a Bethe-Heitler contribution with $m_c = 1.5 \pm 0.1$ GeV.

Two different types of fits are performed in leading and next-to-leading order, NLO, using the DIS$_\gamma$ and $\overline{\text{MS}}$ schemes. In the first fit the hadron-like part of the photon structure is neglected, and only the point-like part, which is evolved from a starting scale of $Q_0^2 = \Lambda^2$, is taken into account. Consequently the only free parameter of the fit is $\alpha_s(M_Z)$. Since the hadron-like part dominates at low x and Q^2, only the data in the region $x > 0.45$ and $Q^2 > 59$ GeV^2 are used in this fit. The second fit uses all data, takes into account both components and fits for (N, α, β, α_s, Q_0^2) using the assumptions, $uds(Q_0^2) = Nx^\alpha(1-x)^\beta$ and $g(Q_0^2) = 0$. Both types of fits give a reasonable description of the data. Within the assumptions made, the quoted theoretical precision on $\alpha_s(M_Z)$ is about 3% and predicted to shrink to less than 2% for Q^2 values larger than 300 GeV^2.

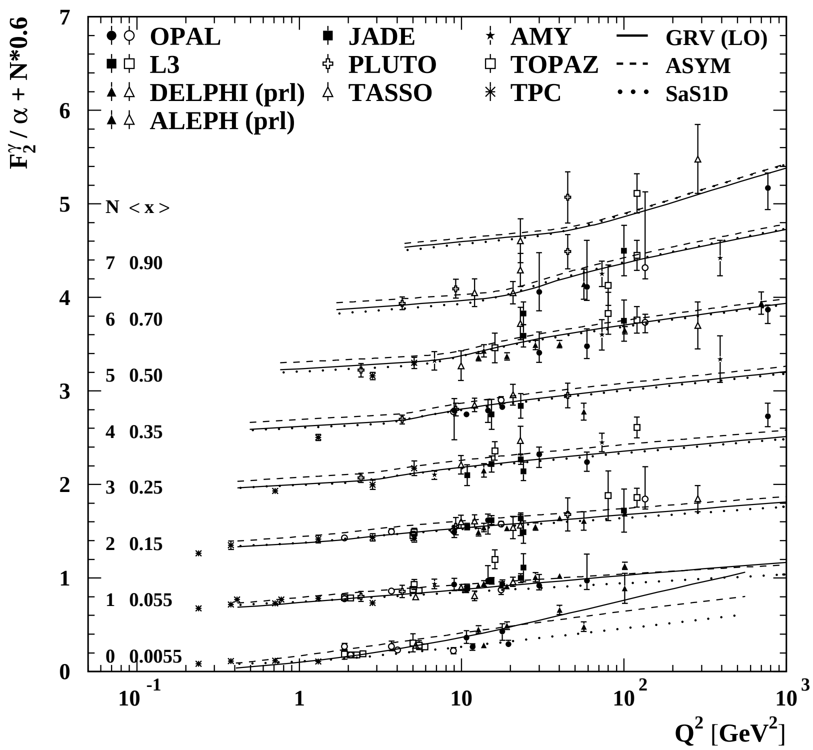

Figure 5: *The world data on F_2^γ as a function of Q^2 in bins of x.*

4 Prospects for F_2^γ measurements

The prospects of future investigations of the photon structure in the context of the planned Linear Collider programme are very promising. The e^+e^- Linear Collider will extend the available phase space, as shown in Figure 6, for the measurement of the Q^2 evolution of F_2^γ at medium x, see [1]. The higher beam energy and luminosity compared to LEP also allows for the investigations of novel features like the measurement of the flavour decomposition of F_2^γ by exploring the exchange of W and Z bosons [7].

5 The charm contribution to F_2^γ

The final OPAL result [8] has been presented of the measurement of the charm component $F_{2,c}^\gamma$ using D^* mesons to identify charm quarks. Compared to the first OPAL result on $F_{2,c}^\gamma$, this analysis is based on improved Monte Carlo models and higher statistics, leading

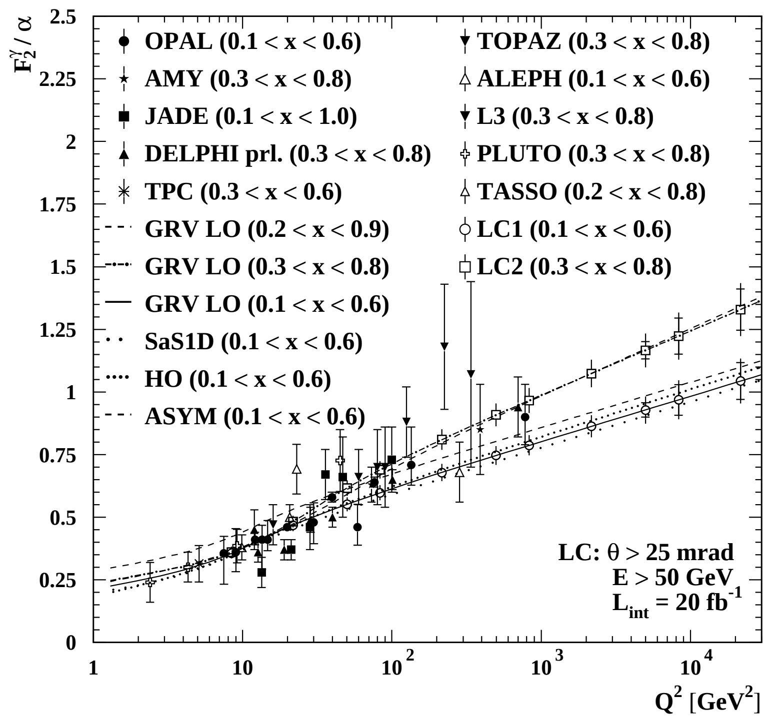

Figure 6: *The expected measurement of F_2^γ at a future Linear Collider.*

to a more precise measurement presented in Figure 7. In a similar way to the structure function for light quarks, $F_{2,c}^\gamma$ receives contributions from the point-like and the hadron-like components of the photon structure. These two contributions are predicted [9] to have different dependences on x, with the hadron-like component dominating at very low values of x and the point-like part accounting for most of $F_{2,c}^\gamma$ at $x > 0.1$.

For $x > 0.1$ the OPAL measurement is described by perturbative QCD at next-to-leading order. For $x < 0.1$ the measurement is poorly described by the NLO prediction using the point-like component alone, and therefore the measurement suggests a non-zero hadron-like component of $F_{2,c}^\gamma$. Increased statistics and a better understanding of the dynamics for $x < 0.1$ are needed to get a more precise result in this region. Also here, to increase the statistics, it would be advantageous to combine the data from all four LEP experiments taken in the same phase space.

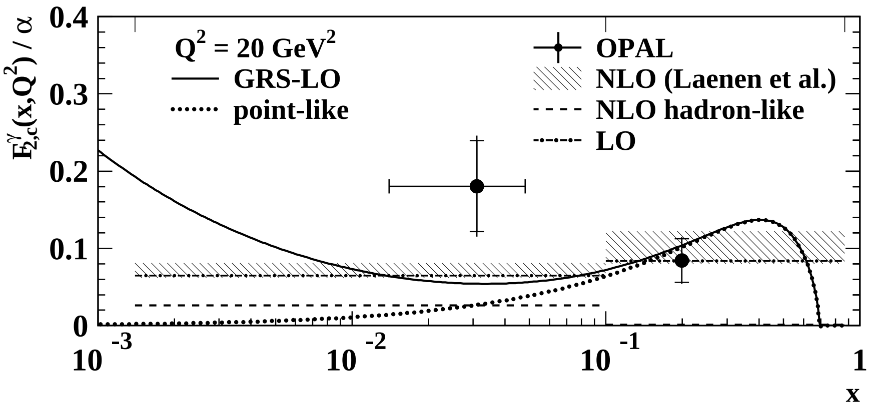

Figure 7: *The measurement of $F_{2,\mathrm{c}}^{\gamma}$ from OPAL.*

6 Electron structure function

For this conference there has been an attempt by DELPHI to access the photon structure by measuring the electron structure function. In this analysis, instead of measuring the electron-photon scattering cross-section by utilising the EPA to account for the flux of the quasi-real photons, the cross-section of electron-electron scattering is studied as functions of Q^2 and x_e, the fractional momentum of the parton with respect to the electron. This quantity is related to x by $x_\mathrm{e} = zx$. The main advantage of this approach is experimental, i.e. the incoming particle probed by the virtual photon is the electron and not the photon. This means that its energy is known, and therefore x_e can be obtained without measuring W. However, there is also a disadvantage in this measurement. The photon structure is obscured because, e.g. the region of low values of x_e receives contributions from both, the region of large momentum fraction x and low scaled photon energy z, and the region of small x and large z. The measurement of F_2^e is performed with a precisions of about 3-20% both for the statistical and the systematic error. So far, no radiative corrections and no bin-centre corrections are applied. The preliminary DELPHI result is consistent with several existing parameterisations of F_2^e, obtained from F_2^γ and $f_\gamma(z, P^2)$ by convolution. The usual exception is the LAC1 parameterisation, which is disfavoured. This investigation serves as a valuable cross-check of the F_2^γ measurements, but does not give more insight into the photon structure.

7 Conclusion

Given the large statistics available at LEP2 energies, the region of phase space covered in the investigations of the structure of the photon is constantly increasing. Despite these large luminosities, for some of the measurements the results are still limited by the statistical error and a combination of the results from several experiments is desirable. This is particularly

true for the measurement of F_2^γ at large Q^2 and the determination of $F_{2,c}^\gamma$. For the first time, the high precision data from LEP have been used in NLO fits to F_2^γ results. With an improved treatment of the experimental data, and the inclusion of the jet data from HERA to better constrain the gluon distribution in the photon, there are good prospects to achieve the first parametrisation of the parton distributions of the photon based on LEP and HERA data in the near future.

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